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Wheeled Mobility and Accessible Transportation

2003 Conference Proceedings

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Chaired by: Steven James Tingus, Director of NIDRR

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CESSI

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Executive Summary

The "Wheeled Mobility and Accessible Transportation Summit" was the first Interagency Committee on Disability Research (ICDR) meeting held to develop a future research agenda based on identified key issues and priorities. It was conducted on July 22, 2003, in Washington, D.C. The one-day meeting took place in conjunction with an accessible transportation forum commemorating the 13th anniversary of the *Americans with Disabilities Act* (*ADA*).

The summit brought together researchers and experts from the fields of rehabilitation science and technology, physical medicine, engineering, architecture and transportation from throughout the country. Attendees included grantees from the National Institute on Disability and Rehabilitation Research (NIDRR) and the Department of Veterans Affairs (VA), as well as policymakers and representatives from disability and transportation-related federal agencies.

Presentations and discussions focused on three main areas related to wheeled mobility and transportation: wheeled mobility usage and interface with the environment; safe and accessible transportation; and standards for public transportation. Topics discussed under usage and interface included: the fit between the user and the chair itself, advanced wheelchair features, and the barriers to full community participation. In the area of safe and accessible transportation, topics discussed were: the use of wheelchairs as seats in motor vehicles, securement systems and safety issues, intelligent transportation systems, and the design for a universal transit system including buses, trains and light rail systems. Topics related to standards issues included: wheelchairs, seating, wheelchair user safety and the Department of Transportation (DOT)'s regulatory process.

After each set of presentations, discussion ensued to better define the research needed to meet intended goals. The discussion focused on: the logistical difficulties in making cutting-edge wheeled mobility and seating systems available and affordable; the need for compatible and appropriate wheeled mobility for paratransit and *ADA*-compliant securement systems; limited access to, or problems associated with, private and public transportation; the need for a universal transit system that will service all people; and the difficulties in coordinating the use of voluntary standards for wheelchairs and seating systems.

Recommendations among the researchers centered on the need for universal standards for wheelchair interface and the need for clinical practice guidelines that comply with reimbursements from Medicare and other third-party insurers. Wheelchairs must also be recognized as a seat in a motor vehicle with federal endorsement for their use in transit. Participants agreed that to better characterize wheeled mobility assistive technology use in transportation, questions in transportation databases must first be modified. Notification of when crashes or incidents occur, through the use of the Food and Drug Administration's (FDA) medical device reporting system, would further benefit the investigation of people seated in wheelchairs. They also suggested that a registry of wheelchair users be developed to assist researchers in answering pertinent research questions such as: anthropometry of wheeled mobility devices; long-term studies on the cause and prevention of secondary injuries from wheelchairs; analysis of risk versus operational issues; the quality of health care and the cost; and the design of mobility for more than one use.

While significant time was devoted to group discussion, which was designed to reach a consensus on research gaps and future needs, it was determined that further follow-up was necessary. Two subsequent teleconferences, which included many of the participating researchers, were conducted to identify and refine key issues and priorities related to wheeled mobility and accessible transportation research. They are included herein.

Nearly all presenters prepared brief papers to complement their talks. The papers and presentations served as the basis for discussion in each area. A collection of edited papers can be found in Appendix A.

Topical Areas Discussed

Wheeled Mobility Usage and Interface With the Environment

Presentations

Title	Author and Title	Affiliation
"Research Into the Effectiveness and Use of Tilt-in Space and Recline Wheelchairs for People With Progressive Disorders"	Rosemarie Cooper Instructor	School of Rehabilitation and Health Sciences Department of Rehabilitation Science and Technology University of Pittsburgh
"Wheelchair Propulsion and Usage"	Sue Ann Sisto Director	Human Performance and Movement Analysis Lab Kessler Medical Rehabilitation Research and Education Corporation West Orange, N.J.
"Optimizing Wheelchair Function for Increased Community Participation"	Richard Simpson Assistant Professor	School of Rehabilitation and Health Sciences Department of Rehabilitation Science and Technology University of Pittsburgh
"Interactions Between the Environment and Wheeled Users"	David Gater, Jr. Assistant Professor	Physical Medicine and Rehabilitation Department University of Michigan Ann Arbor

Discussion

According to Rosemarie Cooper, at a time when wheelchair technology has clinical and functional benefits for users, consumers, practitioners and insurance companies, most are not familiar with the benefits of these interventions and they are either not prescribed or funding is denied. Cooper emphasized that the current state of research must justify such features as power tilt, reclining seating systems and pressure-relieving cushions that adapt to the anticipated needs of users. There is limited clinical knowledge and awareness of how these tools and interventions can be utilized when recommending technology for clients. She and her colleagues in the departments of Rehabilitation Science and Technology, Physical Medicine and Rehabilitation, and Bioengineering believe research to demonstrate the effectiveness and indications for these interventions should be a priority to impact policy changes, increase awareness and ensure people with disabilities have access to proper seating and mobility interventions.

Sue Ann Sisto talked about quality of life and emphasized the need for better instruments to evaluate multidimensional functionality of wheelchair use in the home and community. She believes evaluating psychological well-being is an important aspect of research, as improvement to one's psyche is crucial to integration into the community.

Greater community participation for individuals with disabilities, according to Richard Simpson, can be achieved through improved wheelchair design. This includes additional research in the area of intelligent mobility aids (IMAs), known as smart chairs, which are placed on power chairs to enhance mobility. Consisting of a power base with a computer and a collection of sensors, or a mobile robot base with an added seat, smart chairs are designed to provide navigational assistance to the user assuring collision-free travel and autonomous transport between locations. Richard Simpson added, the most important research question may be, "What would be the effect of long-term use of a smart chair on an individual's mobility and quality of life." Also important is whether smart chairs are effective in training individuals for independent mobility in standard wheelchairs. At the present time, it is unclear how existing standards should be applied to smart chairs, and whether a range of standards is needed to address varied functionality and target populations. The barriers to commercialization include cost, reliability and the inability to navigate unfamiliar environments where drop-offs from curbs and stairs may be encountered.

David Gater, Jr. agreed that while wheeled mobility is liberating, environmental barriers can cause restrictions. He referred to the International Classification of Functioning, Disability and Health (ICF), which was adopted recently by the World Health Organization to demonstrate the relationship between body functions, activities, participation and the way the environment interacts with these constructs. Wheeled users encounter a physical environment that is impacted by natural elements, such as sloped or irregular surface terrain, further modified by weather conditions including wind, rain, heat, cold and snow accumulations. Extreme ambient temperatures also affect the thermoregulatory capacity of many wheeled users, according to Gater, as well as compromising skin integrity due to changes in the density of some seating systems.

The *ADA* has been successful in creating modifications to existing natural and built impediments to the wheeled user and creating standards that increase access to public spaces, jobs and resources. Yet, there are still many important destinations for wheeled users that lack full access. Gater is in agreement with the other researchers that increased participation within the community can improve a person's function. For this to occur, not only is there a need for improved physical access but also for change in social perspectives, politics, culture and economics in order to increase a person's access to appropriate wheeled mobility and, thus, assisting health and function. By categorizing functioning and disability in reference to contextual factors, including the environment and personal issues, the ICF can be effective in successfully demonstrating outcomes in an environment that is not laboratory-controlled.

Safe and Accessible Transportation in Private and Public Vehicles

Presentations

Title	Author and Title	Affiliation
"Occupant Restraint and Safety Systems"	Larry Schneider Senior Research Scientist	Transportation Research Institute University of Michigan Ann Arbor
"Securing Wheelchairs: Recent Developments, Future Challenges"	Douglas Cross Former Accessible Services Manager	Alameda-Contra Costa Transit District Oakland, Calif.
"Accessibility and Intelligent Transportation Systems"	Aaron Steinfeld Human Factors Engineer	Robotics Institute Carnegie Mellon University
"Ingress and Egress From Vehicles"	Ed Steinfeld Director; Director and Professor	Center for Inclusive Design and Environmental Access; Rehabilitation Engineering Resource Center on Universal Design; and Buffalo School of Architecture and Planning
"Categorization and Identification of Critical Research in Wheeled Mobility and Accessible Transportation"	Jay Martin Professor	College of Engineering and Academic Affairs University of Wisconsin-Madison

Discussion

For the past 13 years, the *ADA* has worked to guarantee equal rights for persons with disabilities in employment, transportation, telecommunications, public accommodations and government services. To take this to the next level, in 2001 the *New Freedom Initiative* (*NFI*) emphasized the need for integrating disabled persons into the workforce and community; it also cited transportation as a critical factor in meeting this priority. *NFI* details can be found at: www.whitehouse.gov/news/freedominitiative/freedominitiative.html (last accessed Dec. 19, 2004. A report by Project ACTION (a national program supporting innovation and cooperation in solving transit accessibility issues, funded by the Federal Transit Administration and administered through Easter Seals), and referred to by Gina Bertocci from the University of Pittsburgh Rehabilitation Engineering Resource Center (RERC[1]) on Wheelchair Transportation Safety, indicated that there are 25 million transit-dependent people with disabilities—one-third reporting inadequate transportation as a significant problem.

[1] Rehabilitation Engineering Research Centers (RERCs) plan and conduct research leading to new scientific knowledge and new or improved methods, procedures and devices to benefit people with disabilities. They are engaged in developing and disseminating innovative methods of applying advanced technology, scientific achievement, and psychological and social knowledge, with the goal of solving rehabilitation problems and removing environmental barriers.

With access to motor vehicle transportation key to functioning in society, wheelchair users who are unable to transfer to a motor vehicle seat during transport must use their own wheelchair as a motor vehicle seat. These wheelchairs are not routinely designed to function as seats in motor vehicles. Consequently, wheelchair users are at a greater risk of injury in a crash, or during emergency driving maneuvers, than those using original equipment manufacturer's (OEM) seats. Bertocci and her colleagues are working to avoid injury to the wheelchair user as a potential outcome in a crash.

Features that reduce injury when someone is seated in a wheelchair include: a structurally sound wheelchair; appropriate securement systems, such as four-point strap tie-downs (i.e., four adjustable-length straps that attach to the wheelchair at four securement points by way of floor anchors that insert into anchor tracks or other floor-mounted brackets); occupant restraints that include lap and shoulder belts; and for some users, a head restraint. The long-term goal for wheelchair seats in motor vehicles is crash protection equivalent to OEM vehicle seats. Wheelchair transportation standards focus on two areas—the tie-downs and occupant restraints for the securement systems and the wheelchair itself. Two sets of standards exist for the wheelchair—the national standard set by the American National Standards Institute (ANSI) and the Rehabilitation Engineering and Assistive Technology Society of North America (RESNA) and the international standard set by the International Organization for Standardization (ISO). ANSI and RESNA adopted the WC-19, a wheelchair standard, in May 2000, establishing design criteria, instructions to users, labeling, and test methods. This voluntary standard specifies manufacturers to incorporate four securement points that are compatible with tie-down straps used on the vehicle. It also specifies that wheelchairs be subjected to a 20 g[2] and 30-mph frontal impact crash test with a seated occupant and a reusable tie-down system.

Testing of the WC-19 standard wheelchairs, at the University of Michigan RERC, indicates that chairs weighing 225 pounds or more are having difficulty passing. Common crash test failures include the detachment of seating systems, headrests, footrests and batteries. Compliance problems involve sharp edges near tie-downs, poor lap belt fit and poor access to securement points.

A limitation of the WC-19 standard is that when seating systems are added to the wheelchair after testing, they negate the results. To combat this problem, groups within the standards organizations are developing a method to evaluate the crashworthiness of seating systems independent of a wheelchair frame or base, with the goal of assisting manufacturers in the design of crash-worthy transit wheelchair seating. A database of 259 wheelchair tests conducted at the University of Michigan describe the wheelchairs, the test setup, dummies used, how the wheelchairs responded, the type of seat used in testing and if it failed, and the mode of failure. The wheelchairs tested represent 90 percent of the WC-19 transit chairs on the market today.

Test results, according to Bertocci, indicate a need for better wheelchair design, particularly as it relates to rear- and side-impact protection. Greater attention must also be placed on postural supports, accessories and crash performance. At the present time, little is known from an epidemiological standpoint about whether WC-19 transit chairs actually reduce injury. Lastly, a

[2] The "g" refers to g-force, which is a unit of measurement that is about the same as the acceleration caused by gravity on Earth.

focus is needed on training of users and clinicians to let them know that standards exist and that manufacturers are producing wheelchairs that are transit-worthy.

Douglas Cross, formerly an accessible service manager with the Alameda-Contra Costa Transit (AC Transit) District in Oakland, Calif., one of the largest bus transit systems in the United States, said that people with disabilities have been using the AC Transit District's accessible bus fleet since the mid-1980s. This system has a long, pre-*ADA* history of wheelchair and disability use and cosponsors a large *ADA* paratransit system with the Bay Area Rapid Transit District for public transportation.

Cross pointed out that as travel by passengers with disabilities increases, there is a greater need to eliminate barriers for using bus service, instead of focusing on paratransit. With this in mind, safer and better designed, commercially available, on-vehicle wheelchair securement equipment has evolved. Cross emphasized, however, that the evolution of wheelchair design is at odds with some of these improvements. Few power wheelchairs and scooters provide adequate securement points, recently developed standards by ANSI and RESNA are not well-known, and new designs for securement are only available on a fraction of wheelchair models. As the growing need for devices with proper attachment points escalates for wheelchair users, as well as for manufacturers, dealers and medical funding agencies, several research and development projects are forthcoming to improve the situation. These include testing of innovative securement designs; evaluation of existing securement, occupant restraint and crash testing requirements; and investigation of universal docking solutions. Cross believes it is time for transit systems, disability advocates and transportation regulatory bodies to take a leadership role in guiding new research and implementation of standards.

With 600 to 900 wheelchair users per day boarding the AC Transit system, it is similar to other large West Coast transit systems. Issues related to the use of ADA-compliant securement systems and the need to improve access for wheelchair users led AC Transit to explore the following:

- Creating the Wheelchair Marking Tether Strap Program—AC Transit offers either marking appropriate places for attachment points on chairs with color-coded tape or attaching a fabric webbing tether strap;
- Participating in a Cleveland Clinic Foundation (CFC) securement prototype trial—This pilot project is to incorporate motorized tensioning of tie-down straps to eliminate the failure of improperly tightened straps;
- Purchasing buses with rear-facing wheelchair positions—European-style, low-floor buses featuring boarding at mini-stations (i.e., limited express stops) via multiple bus doors, providing an opportunity for a securement style common in Europe and Canada;
- Retrofitting the existing fleet with newer securement equipment—*ADA*-compliant, manufacturer-improved systems that consist of four tie-down straps, remote release levers, automatic tensioning and convenient stowage; and
- Improving employee training and customer education—AC Transit uses retired buses for securement training purposes and allows passengers to practice boarding, maneuvering and securing their chairs. Passengers are educated about securement with interior advertising cards that explain the six steps of wheelchair securement.

Cross said the WC-19 standard was developed by the Standards Committee on Wheelchairs and Transportation (SOWHAT) and sponsored by ANSI and RESNA. Membership is open to wheelchair and securement manufacturers, researchers, disability advocates and transit system staff. Transit industry participation, according to Cross, however, has been minimal and the committee wants to see a stronger transit role, especially in educating the public about the WC-19 standard.

NIDRR's RERC on Wheelchair Transportation Safety at the universities of Pittsburgh and Michigan involves all interested parties in research and development. They are investigating tie-down and occupant restraint technologies and universal docking concepts that enable wheelchair users to independently secure and release their wheelchairs. Researchers are also investigating the frequency of crash-related injuries on large urban transit buses.

The Center for Urban Transportation Research (CUTR) surveyed 270 transit agencies nationwide and found 90 percent have securement policies and 94 percent utilize tie-downs. In a published report available on its Web site at www.cutr.usf.edu/index2.htm, CUTR found that difficulties in securing wheelchairs are mainly due to a lack of understanding the policy and to uncertainty about whether they should be secured at all. Policy clarification and guidance, as to appropriate wheelchair features for use in transportation, are needed. Continued dialogue to determine priorities, education to emphasize the benefits of proper securement, and "Transit Option" wheelchairs (i.e., wheelchair models with the securement "loops" specified by the WC-19 standard) are the most needed efforts according to Cross. He stressed leadership and consensus-building to meet these common objectives.

Aaron Steinfeld discussed recent advances in intelligent transportation systems (ITS) in personal vehicles for persons with disabilities. The very nature of the systems assist and improve the use of transportation for everyone, including people with disabilities. In the research on the usability and utility of ITS, however, researchers often use older subjects that do not represent all age groups (e.g., younger and middle-aged users with disabilities); therefore, accessibility of ITS applications is largely unexplored. Methodologies for examination should include identification of user needs, guideline development, basic research, reference designs and prototype testing, and standards development. To ensure that new ITS adopted by industry are universally accessible, Steinfeld recommends including the following topics in a research agenda:

- Multifunction dashboard controls that support safe use by drivers whose vehicles have hand controls;
- Driver-vehicle interfaces that support safe interaction by drivers who are deaf, hard of hearing or have speech impediments;
- Active vehicle control (i.e., ITS that shares vehicle control between the system and the user; for example, adaptive cruise control that matches speed with a vehicle traveling in front of said vehicle) and drive-by-wire (i.e., no mechanical linkage between controls and the vehicle) standards to include early integration of alternative vehicle control software and hardware interfaces; and
- Transit information in accessible formats.

Steinfeld believes that ITS applications have potential to be powerful enablers but must be coupled with identifying accessible solutions. Policy and research entities must emphasize accessibility in the early stages of development for the greatest benefits to occur.

Next, Ed Steinfeld made a strong case for universal design (i.e., the design of products and environments to be usable by all people without the need for adaptation or specialized design) as a means to improve accessibility for mass transit. While the ADA has demonstrated the feasibility of accessibility for wheeled mobility, budgetary considerations hamper the ability of mass transit to compete with private automobiles and increase ridership. Improving services and convenience for everyone is a shared goal of mass transit. The accessibility movement and universal design will accomplish this goal, benefiting all customers and reducing the need for costly paratransit.

A good example of universal design is the “stepless” bus. Equipped with a low floor, “kneeling” suspension and ramp access, it facilitates ease of ingress and egress for all riders, not just wheeled mobility users. An advantage, besides its ability to be used by everyone, is that it does not add extra boarding time. This makes bus riding attractive to all customers and allows the wheeled user to be an independent participant.

When examining universal design it is important, according to Steinfeld, to look not only at the design of the vehicle but also the context in which it operates (e.g., station design and operating policies). He pointed out that much could be learned from other countries where transportation issues are being addressed. His paper indicated that in Helsinki, Poland, where there was an existing light rail system with most of the major stops located on islands in the middle of the street, a new tram with a low floor and a wide midcar entry, including a new fare system with automated pay stations at each entry was designed. Midstreet stops were raised off the ground to allow them to be flush with the tram, and ramps were built at the end of each platform and coordinated with pedestrian crosswalks.

A number of problems still must be overcome to make commuter and intercity rail systems completely accessible. Since passenger cars are completely filled with seats, there is no room for luggage or wheeled mobility devices. All compartments have stair access, and there is a gap between the train and the platform. In some cases, there may also be differences in the platform height from station to station. One solution is incorporated in the design of a new train traveling from Denmark to Sweden. It has a low floor, a main entry in the middle of the car at the same level as the station platforms, and folding seats to provide more room for standing riders, wheeled mobility devices, carriages, rolling luggage carts and bicycles. The no-step entry is also equipped with a telescoping gangway, to bridge the horizontal gap, and a wide, automated door.

An effective mass transit system for a low-density community was designed in Curitiba, Brazil, where the heart of the system is a dedicated busway with vehicles that hold up to 350 passengers. This capacity is achieved with a minimum number of seats and buses or trains with up to three connected, articulated cars. A system of “feeder” buses brings passengers to bus or train terminals where the buses and trains travel on radial routes to the city center. This system can be adapted to low-density areas where streets are wide enough to provide dedicated busways.

One major concern raised by Steinfeld is that larger and heavier wheeled mobility devices are being used more frequently and even lighter chairs have cambered wheels that are wider than conventional models. Scooters and power chairs also present ingress and egress problems for mass transit vehicles. Therefore, better communication between consumer advocates, wheelchair manufacturers, vehicle manufacturers, and transit agencies is a necessity to identify solutions to this burgeoning problem. Additional solutions are needed to create design standards, operating guidelines and public education.

Jay Martin emphasized that there are many areas with a need for research and a large number of constituents with specific needs, including wheelchair users, providers of health care, third-party payers, the durable medical equipment industry, the transit industry and government. Social and cultural issues also must be considered in conducting research in the most effective manner, Martin added. He outlined a strategy for choosing research goals that can include all constituent groups, be researcher-guided, and be government-mandated or dependent on a design process. Martin believes in a consortium where all partners must participate in a system design that is universal in nature.

He categorized research needed into two groups: engineering research before a device can be produced, in contrast to design where no additional fundamental information is needed. Other areas are clinical evaluation, sustainable production capability and state-of-the-art research to result in multiple technologies. Martin would prioritize research in the design of more efficient power systems and an integrated restraint system that the user can attach independently. In summary, he recommended assistive technology that is modular and customized, a sustainable level of products as a goal, and a global long-term perspective.

Standards for Public Transportation

Presentations

Title	Author and Title	Affiliation
"Wheelchairs as Seats in Motor Vehicles"	Gina Bertocci Associate Professor	School of Rehabilitation and Health Sciences Department of Rehabilitation Science and Technology University of Pittsburgh
"Standards Related to Wheelchair User Safety"	Larry Schneider Senior Research Scientist	Transportation Research Institute University of Michigan Ann Arbor
"Wheelchair and Seating Standards"	Rory Cooper Professor	School of Rehabilitation and Health Sciences Department of Rehabilitation Science and Technology University of Pittsburgh
"Brief Introduction to Department of Transportation Regulatory Issues"	Annie Glenn Aviation Industry Analyst	Aviation Consumer Protection Division Department of Transportation Washington, D.C. (Office of the Inspector General Department of Transportation Washington, D.C.)

Discussion

User Safety: Larry Schneider cautioned that while federal legislation has increased the availability of public and school transportation for wheelchair users since the mid-1970s, there has not been commensurate safety guidelines. Wheelchair users travel with significantly greater risk of an injury in a motor vehicle crash than occupants who use the OEM vehicle seats and restraint systems, which must comply with minimum crashworthiness design and performance requirements.

Prior to 1993, Federal Motor Vehicle Safety Standard (FMVSS) 222, School Bus Passenger and Crash Protection (Department of Transportation) provided frontal crash protection for students seated on the OEM bus seat but exempted children in wheelchairs. The National Highway Traffic Safety Administration (NHTSA) modified FMVSS 222 in 1993, adding requirements for OEM school buses equipped with wheelchair stations to now have a four-point wheelchair tie-down and a three-point, vehicle-anchored occupant restraint for use with forward-facing wheelchairs. The NHTSA, however, denied a petition to address the design and performance of wheelchairs as seats in motor vehicles.

In the 1970s and 1980s, there was no federal provision for the safe transport of people in wheelchairs in public and private vehicles. So, in the mid-1980s, the Society of Automotive Engineers (SAE) established the Adaptive Devices Subcommittee to develop SAE-recommended practices for aftermarket motor vehicle equipment. After more than 10 years of effort and coordination, according to Schneider, the SAE Restraint Systems Task Group recommended Practice J2249, the Wheelchair Tie-down and Occupant Restraint Systems for Use in Motor Vehicles.

When members of the SAE's task group later recognized that the weak link in the occupant protection system was the wheelchair itself, they formed SOWHAT within the RESNA Wheelchair Standards Committee. The goal to develop a new wheelchair standard that establishes design and performance requirements and test methods was realized with the establishment of the WC-19 standard. Provisions include design and performance requirements related to ease and effectiveness of wheelchair securement and occupant restraint, and the requirement that products must perform successfully in a 20 g and 30-mph frontal impact crash test. To ensure compatibility between wheelchair securement on the chair and securement provided in public vehicles, wheelchairs that comply with the WC-19 standard must provide four easily accessible hook-on-type securement points and be dynamically tested (i.e., a crash test at 20 g and 30 mph).

These voluntary standards are based on occupant protection in frontal crashes and a level of impact testing comparable to government safety standards for passenger vehicles. Currently, RESNA and the ISO are addressing occupant protection for wheelchair riders in side and rear impacts, and the development of a universal docking interface geometry that will replace the four-point, strap-type tie-downs for universal securement.

Wheelchair and Seating Standards: ANSI/RESNA and the ISO began work on wheelchair and seating standards in 1979, according to Rory Cooper. At present there are 26 research standards in development or approved, and an international team of people knowledgeable about wheelchair standards is coordinating and harmonizing ISO and ANSI/RESNA standards. Worldwide standards are necessary to create an international market, assist in removing trade barriers, and expand access to wheelchairs and seating. At the present time, standards are limited to a few countries including the United States, Canada, the United Kingdom, Spain, Germany, Sweden, the Netherlands and Austria. Cooper emphasized the need for greater participation among developing countries where the lack of Internet access and money to travel prevent them from taking part in the standards process. Funding is needed to broaden standards participation beyond the RERCs, the government and manufacturers and for the research to support standards development.

Changes in manufacturing demographics influencing standards include globalization, with most wheelchair components now being manufactured outside the United States. The focus is on cost-reduction engineering, rather than on new innovative technologies, due in part to the interest of third-party payers in competitive bidding to drive prices down. Information technology is also influencing manufacturing with more computerized design and integration of information technology.

Technology in need of standards includes: tilt and recline wheelchairs, pediatric products, power-assist devices, pressure-relieving cushions, alternative batteries, communications standards to transition from analog to digital and serial interfaces (i.e., legacy methods for on-board communications). These are being replaced by universal serial bus (USB) and wireless methods. For example, when a user moves a joystick to go forward, that command must be relayed to the motor. New advanced technologies, such as smart wheelchairs,[3] are also in need of standards. Better collaboration is also needed among organizations responsible for standards, according to Cooper. In the transportation arena, the SAE and ANSI/RESNA are working well together, while in the seating and mobility standards area, there needs to be greater harmony among ANSI, the U.S. Access Board (i.e., an independent federal agency devoted to accessibility in design for people with disabilities) and the American Society of Testing Materials. On the international level, there is a lack of interaction among the interested parties. There is also a need for more specialists (e.g., specialists in wireless communications and computer engineering), clinicians and consumers to be involved in the standardization process.

Cooper would like to see a national translation of standards into design guidelines and a greater push for federal agencies to use wheelchair standards. Wheelchairs are regulated by the FDA as Class I, II and III devices (i.e., general controls, special controls and premarket approval, respectively)—depending on the functional capabilities. Seating systems, however, are not regulated. He hopes that the Centers for Medicare & Medicaid Services (CMS) and the VA will use the standards in their classification of products as well.

Standards are also related to clinical practice guidelines, such as measurement standards that determine the maneuverability of a wheelchair within the space that it will be utilized. Cooper would like to see standards incorporated into clinical practice, implementing them through certification and licensure and integrating them into pre- and post-professional training.

Annie Glenn mentioned that she works in the subject area that is the intersection of passengers with disabilities, the air carriers and their restrictions and obligations, and federal regulations. Her office implements the regulation regarding nondiscrimination of air travelers with disabilities to ensure that carriers are providing passengers with access. Cases they have closed

[3] A smart wheelchair typically consists of either a standard power wheelchair to which a computer and a collection of sensors have been added or a mobile robot base to which a seat has been attached (Simpson, 2005)

recently involve the regulation (14 CFR Part 382, http://a257.g.akamaitech.net/7/257/2422/06jun20041800/edocket.access.gpo.gov/2004/04-24371.htm, last accessed Dec. 19, 2004) requiring boarding, deplaning and connecting assistance for passengers, particularly those with mobility issues. Glenn believes that great strides have been made in redefining regulations and mandating that air carriers make changes to facilitate better accommodations. Other issues related to wheeled mobility are stowage of wheelchairs and batteries, lift issues and damage to wheelchairs.

Key Issues and Priorities By Topical Area

Meeting participants generated a list of 56 research-related issues and needs. The full list appears in Appendix B. After the summit, the researchers participated in two teleconferences, facilitated by the ICDR executive secretary, to identify and refine the key issues and priorities from this original list. The key issues and priorities are listed (in random order) for each area.

Wheeled Mobility Usage and Interface With the Environment

1. Power-assisted wheels for manual-style usage and other secondary conditions of power usage for people in transition as an intermediate style of power.
2. Evidence-based practice guidelines must direct reimbursement policy (so that people can obtain wheelchairs and seating systems through third-party carriers that can best assist their activities of daily living without negatively impacting their medical condition) while still addressing the standards of clinical practice.
3. Use of ICF framework and structure within research and clinical applications in all phases of wheelchair usage.
4. Increased knowledge and understanding of smart wheelchairs with respect to how they identify environmental situations and interact with the setting.
5. The impact of smart chairs on the mobility of people with a combination of physical, perceptual and cognitive disabilities.
6. Development of advanced mathematical and computer modeling in rehabilitation to be used for design of controls, upper extremity use for manual propulsion, smart chair operation in different environments, virtual reality and environmental detectors.
7. Lack of research funding for physical fitness for wheelchair users. An example of how to potentially address this issue would be to increase coordination between NIDRR and physical fitness programs, such as the President's Council on Physical Fitness and Sports. (A resource guide is available at www.usc.edu/dept/gero/RRTConAging/paper1.html#anchor1, last accessed Dec. 19, 2003.)
8. Intervention studies that pertain to wheeled mobility and interface in the community with larger sampling and randomized clinical trials.
9. Anthropometry of wheeled mobility devices through the RERC on Universal Design at Buffalo and the U.S. Access Board, the government entity supporting this research, including coordination of resources across the government.
10. Increased information and long-term studies to investigate the cause and prevention of secondary injuries as a result of assistive technology use, such as arm pain in individuals who propel manual wheelchairs.

Safe and Accessible Transportation in Private and Public Vehicles

1. A registry of wheelchair users willing to answer research questions to develop a population that facilitates research which complies with the *Health Insurance Portability and Accountability Act's* (*HPPA*) (http://aspe.hhs.gov/admnsimp/pl104191.htm, last accessed

Dec. 19, 2004) privacy regulations; training of users to become active participants in framing research questions and design.

2. Identification of crashes or incidents in a timely manner for in-depth investigations of people seated in wheelchairs; use of the FDA's medical device reporting system (MDRS) for notification of when adverse events occur; the creation of an MDRS-capture transport accident subset, specifically for a listing of accidents that involve the transport of people in wheelchairs.
3. Research on risk analysis for a better balance of risk and operational issues based on vehicle type and transportation mode.
4. Taking advantage of software and multifunction interfaces to support easy aftermarket modification; standards development for vehicle modification and software interfacing. (For example, car rentals with hand controls should be universal and able to be installed quickly and easily.)

Standards for Public Transportation

1. The establishment of reimbursement mechanisms to pay for wheelchairs that meet standards to serve as seats in a motor vehicle.
2. Topical studies to identify means of reducing the incidence of injury, such as:
    a. The Agency for Healthcare Research and Quality (AHRQ)'s study of quality of health care and cost.
    b. Case studies of real-world incidents for manufacturers and providers.
    c. Education of people in absence of federal requirements.
    d. Education of manufacturers about information derived from studies.
3. Research of accident investigation data to identify successful safety features.
4. Information on best practices in universal design (i.e., the process of creating products which are usable by people with the widest possible range of abilities, operating within the widest possible range of situations) in transportation.
5. Research to determine whether standards should accommodate trends in larger-wheeled mobility devices, or if the devices should be designed to meet basic requirements for use on public transportation vehicles.
6. Designing mobility devices for different uses and encouraging people to have more than one wheeled-mobility device.
7. Labeling wheelchairs to indicate what standards they meet, so consumers will be informed of the implications.
8. The design of equipment to fit the environment and accommodate tie-downs.

Appendix A:
Background Papers by Topical Area

Topic: Wheeled Mobility Usage and Interface With the Environment

Research into the Effectiveness and Use of Tilt-in Space and Recline Wheelchairs for People With Progressive Disorders

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There have been great advancements in wheelchair technology over the last decade that have clinical and functional benefits for people with disabilities. The problem, however, is that consumers, practitioners and third-party payers are not well versed in the benefits of these interventions, and therefore they are often not prescribed or funding is denied. The reasons for this are multifaceted, including outdated Medicare coverage policies, limited research demonstrating effectiveness, and the limited general practitioners' knowledge or awareness. It seems reasonable that research demonstrating the effectiveness and indications for these interventions should be considered a priority to influence policy changes, increase awareness, and ensure that people with disabilities have access to proper seating and mobility interventions.

Vulnerable populations that illustrate this issue are people with progressive neuromuscular disorders such as people with multiple sclerosis (MS) and amyotrophic lateral sclerosis (ALS). These individuals often need powered wheelchairs equipped with multiple-powered seat functions, including tilt-in space, reclining backrests, elevating leg rests and seat elevators.

A little over 5,000 people in the United States are diagnosed with ALS each year. It is estimated that as many as 30,000 Americans may have the disease at any given time. The life expectancy of an ALS patient averages about two to five years from the time of diagnosis according to the ALS Association. MS is the most common cause of disability in young adults other than trauma, with a prevalence of 350,000. Although MS causes a wide variety of neurological deficits, ambulatory impairment is the most common form of disability (Noseworthy et al. 2000, 938–52). Reduced mobility was associated with reduced quality of life and reduced social activity in people with MS (Aronson 1997, 74–80).

Clinicians who plan for the progression of the disease consider features such as power tilt and reclining seating systems in addition to upgradeable controls, pressure relieving cushions and future options such as a vent tray—allowing the system to grow and adapt to the anticipated needs of the user. They justify the tilt-in space and recline features based on current states of research.

It is well accepted clinically that tilt-in space seat frames and reclining back supports, whether used separately or in combination, have physiological and functional benefits and disadvantages. Tilt-in space alone is beneficial to provide postural stability and comfort, reduce pressure and shear, and allow for gravity-assisted repositioning and realignment. This, however, also can impede function and promote primitive reflexes. Recline alone can reduce pressure in the buttocks and allow for a recumbent position, but it can also cause people to slide out of the seat and increase shear. A combination tilt and recline system also has similar advantages and disadvantages. Sprigle and Sposato prepared a comprehensive review article of the evidence that exists supporting these seating systems (Sprigle and Sposato 1997, 99–122).

Another researcher studied the effects of various seated positions and found that the greatest reduction in pressures and shear forces accompanied a 50 degrees forward lean (Hobson 1992, 21–31). This posture, however, is not feasible for people who lack the trunk control to assume it. Pressure alone was reduced significantly with 120 degrees of recline but caused significant shear, which could result in a person sliding out of the chair. Twenty degrees of tilt was significant in reducing shear, and perhaps more tilt would reduce shear forces further. A combination of tilt and recline could further reduce pressure and shear. Researchers studied the effects of recline and found it to increase shear in the seat (Gilsdorf et al. 1990, 239–46). They also found that transitioning to an upright position increased shear and therefore a likelihood of the person sliding out of the chair. Nachemson found decreased intervertebral disc pressure by reclining the back from 80 to 130 degrees, leading to increased comfort; however, stability was further improved with six degrees of seat tilt to counteract the tendency to slide out of the seat when reclined (Nachemson 1975, 129–43). Further research found that people who sat in wheelchairs with a semireclined back had a tendency to assume a posterior pelvic tilt, kyphotic spine and flexion of the neck in order to assume a visual orientation level with the environment (Pope 1985, 124–31). This provides good evidence to consider tilt with recline if recline is being recommended, and that recline alone can cause significant shear and the potential for people to slide out of the chair. Tilt is therefore preferred over the use of recline when it comes to reducing pressure and shear as well as for maintaining or adjusting postural alignment or stability.

Upper extremity function in a tilted position was found to decrease the functional effects of tilt-in space for children with cerebral palsy (Nwaobi 1987, 1209–12). Results suggest that adjustable tilt (e.g., being tilted back) may assist in pressure relief and postural readjustment; however, it is not a functional position to be continuously maintained in, and people need to tilt more upright in order to engage in activities. Using videofluroscopic imaging, Hardwick et al. provided clinical examples as to the benefits of assuming various positions to assist with swallowing and digestion. Schunkewitz et al. studied the effects of tilt and recline on lower extremity edema and found some improvements in venous stasis in a small sample of three people with spinal cord injuries. The lack of sympathetic muscle tone and dependent position of the lower extremities put people with lower extremity paralysis at risk for deep venous thromboses and edema. Sprigle and Sposato further discuss the benefit of tilt and recline to address the issues of orthostatic hypotension. There also exists a significant amount of expert opinion related to the indications and contraindications for tilt and recline systems (Kreutz 1997, 29–32; Lange 2000, 1–3; Pfaff 1993, 23–27; and Ross 1996, 34–36).

Nevertheless, the current state of research is limited and inadequate as a tool for clinicians. This can partially be explained by the fact that research was conducted in a controlled laboratory setting. It is therefore unknown if after being given these items if consumers are actually using them. If the consumer uses the tilt feature, it is also unknown if the degree of tilt provides adequate pressure relief. To date, there has never been a study testing the amount of use tilt-in space and recline systems receive. We need further studies to fill this important void in the literature and provide clinicians with research evidence that is effective in supporting the justification for their seating recommendations.

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Optimizing Wheelchair Function for Increased Community Participation

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Introduction

There are a number of ways in which the current state-of-the-art in wheelchair design could be improved, leading to greater community participation for individuals with disabilities. So many in fact, that it is worthwhile mentioning some of the topics that will not be discussed, including:

- New power sources with increased longevity and durability;
- More versatile wheelbases, including wheelbases that provide four-wheel steering, omni-directional travel, or the ability to climb or descend stairs and curbs;
- Improved controllers for power wheelchairs; and
- New materials for wheelchair frames and wheels, which are lighter and more durable.

What this paper will focus on is the need for additional research in the area of intelligent mobility aids (IMAs). The term IMA encompasses a wide variety of mobility devices, which make use of technologies originally developed for mobile robots, to enhance the mobility of individuals with disabilities. This paper will focus on IMAs that are based on wheeled mobility devices, but it should be noted that IMAs have also been designed for ambulatory individuals—primarily individuals with visual impairments (Lacey et al. 1998, 211–20).

Almost all IMAs based on wheeled mobility devices are based on the power wheelchair and are referred to as smart wheelchairs. A smart wheelchair typically consists of either a standard power wheelchair base to which a computer and a collection of sensors have been added, or a mobile robot base to which a seat has been attached.

Smart wheelchairs have been designed to provide navigation assistance to the user in a number of different ways, such as assuring collision-free travel, aiding the performance of specific tasks (e.g., passing through doorways), and autonomously transporting the user between locations. Smart wheelchairs have also made use of a wide range of sensing technologies—including sonar, infrared, laser scanning, computer vision and global positioning systems. Despite these differences, there are a number of design and research issues that all smart wheelchairs share.

Research and Design Issues

While there have been many smart wheelchairs designed as research projects, only one has made the leap to commercial product. This device (www.smilerehab.com) is limited to following tracks laid on the floor with tape. The barriers to commercialization include cost and reliability, particularly for smart wheelchairs that are intended for use in unmodified, unfamiliar environments. A particularly important design challenge is to develop an inexpensive, yet extremely reliable, method for identifying drop-offs (e.g., stairs, curbs, holes). Existing solutions are either too expensive or not sufficiently reliable across different surfaces and lighting conditions. This limits smart wheelchairs to environments that can be controlled to eliminate the potential of encountering a drop-off.

Another important design decision is whether to provide multiple task-specific operating modes or a single general-purpose operating mode. Smart wheelchairs, which provide multiple operating modes, are able to accommodate a wider range of needs and abilities but present the added requirement of selecting the most appropriate configuration for a given task. The responsibility for selecting the most appropriate operating mode must then be performed by the user or the smart wheelchair.

Smart wheelchairs represent an excellent platform for supporting alternative input methods, which are not feasible on standard power wheelchairs. An excellent example is voice control, which has been tried on many occasions on standard wheelchairs without success (Amori 1992) but has been used successfully on a smart wheelchair (Simpson and Levine 2002, 122–25). Other potential input methods for smart wheelchairs that are being explored include eye gaze, electrooculogram and electromyogram.

Perhaps the most important research question, which has yet to be addressed, is the actual effect of long-term use of a smart wheelchair on an individual's mobility and subsequent quality of life. This question is complicated by the differing goals of each smart wheelchair. For example, smart wheelchairs that "ferry" the user from one location to another are aimed at a much different user population than smart wheelchairs. Smart wheelchairs prevent collisions with obstacles but rely on the user to plan and execute the path to a destination. In each case, users' goals and alternatives to a smart wheelchair will differ requiring very different cost-benefit calculations. All of this is further complicated by the need for simple, widely adopted outcome measures for assistive technology of any stripe.

A related question is, what role (if any) can smart wheelchairs play in the process of training individuals for independent mobility in standard wheelchairs? Several smart wheelchairs (including the only commercially available smart wheelchair) have been developed explicitly to serve as training tools with the idea that the assistance provided by the smart wheelchair is gradually reduced until the user can operate a wheelchair without any assistance at all. The question, however, is similar to whether training wheels can actually help a child learn to ride a bicycle. Is it possible that learning to operate a smart wheelchair may not actually teach the skills needed to operate a standard wheelchair at all?

Finally, the issue of how existing standards should be applied to smart wheelchairs and what new standards might be necessary, remains open. Given that each smart wheelchair is developed with different functionality and is aimed at a different target user population, there may need to be a range of standards for different types of smart wheelchairs.

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Interactions Between the Environment and Wheeled Users

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Wheeled mobility can be very liberating for the required user and yet restricted by environmental barriers of various types and degrees. The International Classification of Functioning, Disability and Health (ICF) has recently been adopted by the World Health Organization (WHO) to more clearly demonstrate the relationship between body functions, activities and participation, and the specific ways in which the environment can impact each of these constructs (WHO 2001). Environment is comprised of the physical, social and attitudinal setting in which people live and conduct their lives, and these three factors may be considered as either facilitators or barriers to wheeled mobility. The purpose of this paper, therefore, is to review the relationships between the environment as defined above and the wheeled user.

The physical environment encountered by wheeled users includes elements which are natural in occurrence, as well as those which are purposefully constructed or modified by man. Surface terrain may be smooth or irregular, flat or sloped, dense or soft, and each of these characteristics may be modified by ambient temperature and precipitation to which it is subjected. As an example, a hard smooth surface which is relatively easy for wheeled mobility when warm and dry may become relatively impassable under conditions of extreme cold, wind and high accumulations of soft snow.

Natural terrain may be comprised of many elements arranged in various permutations and altitudes including dirt, rock, gravel, sand, water, grass and other vegetation. Wheeled mobility may be further altered by natural conditions of wind, rain, snow, heat and cold. Nonetheless, wheeled users may have similar desires for exploration of natural wonders and terrain as persons of biped capacity do. The wheeled user, however, is subject to limitations in power production, application of torque, surface friction, changes in altitude relative to wheel and axel circumference and height, frame attitude (i.e., width, height and length), turn radius, postural stability and center of gravity. The wheeled user who relies exclusively upon upper extremities for propulsion and transfers is, therefore, subject to upper extremity tendonopathies, osteoarthritic changes and mononeuropathies at the wrists and elbows. In addition to upper extremity overuse syndromes, vibration and postural instability may contribute to accelerated degeneration of spine, pelvis and skin integrity; these latter effects also may impact users of powered mobility devices.

Purposefully constructed or altered terrain include graded dirt, gravel and asphalt roadways, concrete sidewalks, walkways, curbs, steps, ramps and various forms of indoor and outdoor flooring comprised of wood, stone, tile, carpet and linoleum. Specifically created to enhance biped access, some of this man-made terrain may unintentionally restrict wheeled mobility (e.g., curbs, steps and plush carpet). In recent years, builders and engineers have been required to comply with guidelines for wheeled mobility access to private and public facilities (Code of Federal Regulations 1994). Subsequently, access to these facilities should include curb cuts, ramp slopes with a minimum ratio of 12 inches length per each one-inch rise, and landings at the top of ramps of at least five by five feet in area. Additionally, these standards have paved the way for wheeled access to private, public and commercial parking facilities, doorways, aisles and hallways, workspaces, kitchens and bathing and toileting facilities. As such, doorways should be constructed at least 36 inches in width, and hallways constructed to a minimum width of 48 inches; workspaces (such as kitchens, computer stations and phone booths) must be of appropriate height, width and length with space underneath to accommodate wheelchairs. Restroom facilities should provide access for functional use (e.g., grab bars, levers to flush toilet, appropriate sink height and lever access, and mirrors set low enough to accommodate wheeled users). Yet, despite implementation of these access standards, many physical barriers to independent mobility and function remain for wheeled users. A recent study cited drugstores, health professionals' offices, friend's houses, restaurants, libraries and churches among some of the more difficult to reach destinations for wheeled users (Meyers et al. 2002, 1435–46).

Weather conditions of extreme ambient temperatures, rain, ice and snow further compound wheeled mobility issues, particularly as many wheeled users also have poor thermoregulatory capacities (Armstrong et al. 1995, 211–16; Shirado et al. 1995, 408–14). Hence, a wheeled device that also might assist the user in thermoregulation may be desirable. As well, the user's seating system or cushion is subject to change relative to the ambient environment, such that certain gel cushions may become more or less dense under conditions of extreme cold or heat, potentially compromising skin integrity (Ferrarin et al. 2000, 31–34; Odderson et al. 1991, 1017–20). Similarly, changes in altitude can alter pressure characteristics within air cushions.

In addition to the *Americans with Disabilities Act* (*ADA*) access standards, physical facilitators to wheeled mobility include motorized propulsion, stand and recline systems, postural support, and wheels of varying camber, radius, width and tread, and cushions to maintain skin integrity (Minkel 2000, 701–09). Unfortunately, these facilitators often increase the cost, weight or dimensions, or both, of the device which may create additional barriers to wheeled mobility.

Aspects of social and attitudinal environment also directly impact the wheeled user's mobility. Legislation within the United States has recognized the need and facilitated access for wheeled mobility through the *ADA* and *ADA* Access Standards, providing equal access to public spaces, jobs and resources. While many institutions, businesses and builders have voluntarily complied with the *ADA* Access Standards, some have done so grudgingly because of the additional time, space and expense required. Because the current standards do not apply to preexisting facilities, barriers remain to those structures completed in the pre-*ADA* era. Nonetheless, more of our society is becoming aware of the benefits of wheeled access, and recent wheeled technology developed for able-bodied users may facilitate additional changes in access standards. Eventually, societal attitudes toward wheeled mobility will be modified through political, judicial, economic, social and cultural parameters. These attitudes also must be flexible to accommodate changes in the wheeled user's functional abilities as he or she ages or develops comorbidities (Davies et al. 2003, 286–90). Ultimately, relational models of wheeled mobility such as that proposed by Routhier et al. (2003, 19–34) may be required to ensure optimal environments for individuals and groups utilizing wheeled mobility.

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Topic: Safe and Accessible Transportation in Private and Public Vehicles

Securing Wheelchairs: Recent Developments, Future Challenges

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Abstract

The need to accommodate travel by passengers with disabilities on fixed-route transit is increasing. This includes the need to eliminate barriers faced by many individuals in effectively using bus service instead of paratransit. Commercially available on-vehicle wheelchair securement equipment has evolved over the past few years. Several new designs make securement safer and easier to use than the first generations of systems that complied with the *Americans with Disabilities Act* (*ADA*).

The evolution of wheelchair design, however, is at odds with some of those improvements. Many new power wheelchairs and scooters do not provide adequate securement points. Recently developed standards to include attachment points on mobility aids are not well known, and the new designs are available on only a fraction of wheelchair models.

Several research and development projects are underway to improve the situation. These include the testing of innovative new securement designs; evaluation of existing securement, occupant restraint and crash testing requirements; and investigation of universal "docking" solutions. Meanwhile, there is a fast-growing need to find a way for wheelchair users, manufacturers, dealers and medical funding agencies to offer and use devices with proper attachment points.

The transit industry has been only marginally involved in these development efforts but continues to be the frontline for dealing with securement problems. It is becoming crucial for transit systems, disability advocates and transportation regulatory bodies to take a leadership role in guiding new research and implementation of standards.

Transit Service Experience and Solutions

Alameda-Contra Costa Transit (AC Transit) traditionally has served a large wheelchair-using customer base and has had a fully accessible bus fleet since the mid-1980s. The system experiences between 600–900 daily wheelchair users out of a total daily ridership of over 225,000. This level of wheelchair usage is similar to other large West Coast transit systems, many of which were lift-equipped prior to the passage of the *ADA*. Systems in other parts of the country have started to experience more wheelchair demand, which will continue to grow as paratransit and other community resources are stretched.

Issues related to the use of *ADA*-compliant securement systems, along with an increasing general need to improve access by wheelchair users, led AC Transit to explore a variety of approaches including the following projects.

- Wheelchair Marking and Tether Strap Program
  In 2001, AC Transit began offering a free marking and tether strap program for wheelchair users. Passengers make an appointment to have their chairs examined at AC Transit's offices or at one of several disability-oriented agencies throughout the service area. AC Transit staff who are familiar with wheelchairs and bus securement equipment work with customers to mark appropriate attachment points on their chairs with color-coded tape.

  If there is no good place for attachment of belts or hooks, a fabric webbing tether strap is installed permanently on the mobility aid. An informational brochure is distributed to customers and local agencies and is available on the AC Transit Web site: www.actransit.org/pdf/securement.pdf (last accessed Dec. 19, 2004).

  The need for this type of program increased with the advent of hook-style securement equipment for fixed-route buses (hooks have been more common on paratransit vehicles). Hooks afford easier one-handed attachment by drivers or attendants in comparison with the older seat-belt-buckle-style straps. Hooks, however, are less versatile and encounter many more situations where there is no adequate attachment point.

- Cleveland Clinic Foundation (CCF) Securement Prototype
  AC Transit is one of several transit and specialized transportation providers participating in a pilot program of this new system. The CCF design incorporates motorized tensioning of the tie-down straps which eliminates the common failing of manual systems to be properly tightened. Passengers can actuate a nearby electrical switch which both tightens and releases the straps.

  Other aspects of the system are designed for those passengers who have some hand and arm ability to perform without assistance. This also gives passengers greater freedom to unsecure themselves where tensioning of straps is not a factor. Field testing and evaluation of the system should be completed in 2003. The National Institutes of Health (NIH) funded the project.

- European-style Rear-facing Wheelchair Positions
  AC Transit is purchasing European-style low-floor buses for use in new Bus Rapid Transit (BRT) service. This new service will feature boarding at "mini-stations" via multiple bus doors with the goal of faster boarding and limited express stops. AC Transit saw this as an opportunity to try the rear-facing securement style common in Europe and Canada.

  Two securement stations are located on the same side of the new bus, with easy access via a ramp in the second door. This eliminates the entry area constrictions common to traditional front boarding designs. The forward-facing securement area uses traditional belt-type securements. The adjacent rear-facing station features a padded backrest with folding armrest, grab rails and seat belts. This design is intended to provide containment in the event of sudden stops or crashes instead of relying solely on tie-down straps to hold the wheelchair in place.

The rear-facing station is configured also to use *ADA*-style securement straps and to be used as an optional forward-facing station in cases where passengers are not able to ride backward for physical reasons. The regular seating areas throughout the bus feature rear-facing seating in opposing pairs. Therefore, stigmatization of the wheelchair user by being forced to ride backward should not be an issue.

The vehicles were delivered to Oakland in 2003. Initial rides by wheelchair users on two prototype models in late 2002 were very positive, despite some consumer apprehension about how such a different new layout would work. AC Transit expects to participate in research and evaluation of this approach in anticipation of interest in it becoming an accepted United States practice, especially among BRT operators.

- Retrofitting Newer Securement Equipment
  Over the past few years, manufacturers have improved securement systems. *ADA*-compliant systems typically consist of four tie-down straps. New models have become easier to use and help alleviate frustration among drivers and passengers. New products, such as American Seating's A.R.M, Q'Straint's QRT, Sure-Lok's RTT Solo and TSI's 5200, have features such as remote release levers, automatic tensioning and convenient stowage when not in use. Some of the basic ergonomic problems of strap-type systems, however, have not been solved yet. The physical issues of bending, kneeling, pulling, reaching and grasping to perform securement continue to be barriers to acceptance and can even result in injuries.

  AC Transit is considering retrofitting some of its existing fleet with newer equipment and is aware of at least a few other transit systems that have done so. One objective is to foster a more standardized experience for drivers and passengers. The tendency of receiving the "latest and greatest" products with each new bus purchase has resulted in a variety of clamps, straps, hooks, arms and levers for users to decipher. Some of the principles of older systems, such as wheel clamps, are diametrically opposed to the principles of strap-type systems which must not be attached to wheels.

- Improving Employee Training and Customer Education
  Training and education are keys to proper use and acceptance of wheelchair securement systems. AC Transit has tried a variety of approaches and continually looks for new and better methods. Many transit systems have built practice rigs for use at training centers or in driver rooms. AC Transit was able to employ several retired buses as securement training buses.

  One training bus is placed at each bus yard. Each one contains three securement stations with a combination of all of the types of equipment in the fleet. Using actual buses provides the most realistic environment including the space limitations encountered in actual service. The training buses are used for practice and re-instruction of drivers who have questions or are involved in complaints about securement. In addition, new drivers are trained with a variety of wheelchair styles on each of the types of buses in the fleet.

Some transit systems use a mock or actual bus in consumer travel training programs or for conducting functional assessments of paratransit applicants. AC Transit frequently assists customers who have new wheelchairs or are new to the area by allowing them to practice boarding, maneuvering and securing their wheelchairs on a variety of buses in a bus yard.

Educating passengers about securement is accomplished by many transit systems in a special accessibility guide or brochure. AC Transit uses an interior advertising card on both sides of each bus to explain the six steps of wheelchair securement. The card explains how securement can best be done and that drivers must provide assistance in doing so. It includes a statement that passengers must allow their chairs to be secured, and that seat and shoulder belts are at the passenger's option. This covers recent Federal Transit Administration (FTA) guidance stipulating that transit systems must have a stated policy if they intend to enforce the *ADA* provision to refuse service to any passenger who will not allow their wheelchair to be secured.

Standard for Transit Wheelchairs

The WC-19 standard, Wheelchairs Used as Seats in Motor Vehicles, was approved by the American National Standards Institute (ANSI) in May 2000 and is now a voluntary U.S. national standard. It specifies strength and geometric requirements for at least four securement points, and occupant restraint anchorage points that can withstand the forces of a 20 g and 30 mph impact, as well as geometry that can receive a securement hook. The standard covers design requirements, test procedures and performance criteria related to frontal impact performance and accessibility to motor vehicles and stability during normal vehicle travel.

So far, only a limited number of wheelchair models are available with the securement loops specified by the WC-19. Manufacturers call these models the "Transit Option." It is not generally available on power wheelchairs or scooters that are commonly used by transit passengers. Some consumers have reported medical funding entities denying coverage of the option which has only a marginal additional cost. This is partially due to the lack of understanding of the need for securement while traveling and the fact that wheelchairs have not had such features in the past. The problem is compounded by the fact that manufacturers have traditionally labeled wheelchairs as "non-transportable," wary of liability issues and the high cost of crash testing.

The WC-19 standard was developed by the Standards Committee on Wheelchairs and Transportation (SOWHAT), which is sponsored by the ANSI and the Rehabilitation Engineering and Assistive Technology Society of North America. This group also provides official United States input to the International Organization for Standards. Membership is open to interested parties and consists of wheelchair and securement manufacturers, researchers, disability advocates and transit system staff.

The author of this paper is currently a member. More information is available on the Wheelchair Standards Information Web site (www.wheelchairstandards.pitt.edu).

Transit industry participation in the SOWHAT has been minimal in the past, and the committee has identified the need for a stronger role for transit, especially in the area of educating the public about the need for the WC-19 transit option. Other topics being addressed for new standards are testing of aftermarket wheelchair seat assemblies and design geometry for potential universal docking securement mechanisms.

Research and Development

Wheelchair Safety Research Initiative

Several universities and research organizations have investigated various aspects of securing wheelchairs and restraining wheelchair occupants on public transportation. Some of the researchers also are involved in the standards development described above. In 2001, the National Institute on Disability and Rehabilitation Research (NIDRR) awarded a five-year grant for a Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation Safety to the University of Pittsburgh and the University of Michigan's Transportation Research Institute.

The RERC program includes a comprehensive research and development effort that involves consumers, manufacturers, students, clinicians, transport providers and rehabilitation technology experts. It also includes information dissemination, training and technology transfer using personnel, media and facilities at the University of Pittsburgh. Information is available on the RERC Web site (www.rercwts.pitt.edu).

RERC tasks include the investigation and development of new wheelchair tie-down and occupant restraint technologies. Included are wheelchair-integrated restraints and universal docking concepts that can enable wheelchair users to independently and quickly secure and release their wheelchairs and use an effective occupant restraint system without the need for assistance.

Researchers at the RERC are considering the development of lower-severity frontal crash-test standards for securement systems used only on large buses. The current standards for wheelchair securement require testing at a severity of 20 g and 30 mph, which is comparable to federal safety standards for personal passenger vehicles including vans and minivans. A lower level of crash severity may be appropriate for larger buses and may allow the development of securement systems which are more acceptable to the operational demands of public transportation systems.

RERC researchers also are investigating the frequency of crash-related injuries on large urban transit buses. This will help determine the potential risks associated with very low-g securement or facing wheelchair occupants backward against padded structures when traveling in city-type buses.

The docking concept holds particular interest for public transit systems. A few early attempts at developing and marketing such systems encountered many issues. Not the least of these issues was the need for a standardized attachment point on an ever-increasing variety of wheelchair shapes and sizes. However, a practical docking system could alleviate many of the drawbacks of traditional tie-down systems.

Study of Transit Industry Securement Issues
The Center for Urban Transportation Research (CUTR) at the University of South Florida recently published the report "Synthesis of Securement Device Options and Strategies" (#416-07) related to securement and barriers among public transit agencies. The CUTR surveyed 270 transit agencies, inquiring about general agency policies, and found that 90 percent have securement policies and 94 percent actively utilize tie-downs. Over half of the respondents reported ongoing difficulties in securing wheelchairs, especially the "scooter"-type (which are both unstable as seats and difficult to secure). The study is available on the CUTR Web site (www.cutr.usf.edu/index2.htm).

In analyzing the reasons for difficulties in securing wheelchairs, the CUTR study found that many people do not understand policies, and wheelchair users are frustrated and uncertain as to whether they should be secured or not. The study concluded that policy clarification from the U.S. Department of Transportation is needed, as well as guidance as to the types of wheelchairs or features that are appropriate for use in transportation such as the WC-19 transit option. This included an observation that voluntary steps will probably not be enough, pointing to the need for some type of mandatory requirements. The study also concluded that more consistency across vehicle securement devices is needed.

Other Research
In addition to the CCF's NIH-funded development of securement systems, Easter Seals' Project ACTION and the U.S. Transportation Research Board have funded various securement-related projects. Investigation of the European-style rear-facing securement option currently is being covered in a "Synthesis of Practice" (i.e., a compilation of studies on current practice in the field of highway transportation and transit) study, under the board's Transit Cooperative Research Program. Other studies have probably been done under the auspices of a variety of organizations, but there is no central clearinghouse for such information as of yet.

Next Steps

Transit systems across the United States are likely to face mounting safety and driver or customer comfort and convenience issues unless wheelchairs and securement technology are brought more in line with each other. The path to "practical and painless" securement of wheelchairs on transit vehicles is not clear. Two things, however, are clearly needed to begin moving in a cohesive direction—dialogue and education.

Dialogue is needed to determine what the priorities should be, what kinds of standards are needed and how any new standards will be implemented. This should stem from an honest evaluation of the risks to which wheelchair-using transit riders are exposed and what kind of protection they need, balanced with the need for freedom of movement that the general public enjoys.

Education on the benefits of proper securement and the need for WC-19-specified "Transit Option" wheelchairs, as well as on other potential improvements, is needed for wheelchair users and manufacturers, securement equipment and vehicle suppliers, transit managers, and medical funding and regulatory entities. Also needed is leadership and consensus building toward common objectives.

The CUTR report recommendation that some type of mandatory regulation will be needed brings up questions:

1. Who and what should be regulated, and how could it be enforced?
2. Will collaborative efforts be enough?

The transit industry will be on the front line of any of these issues since all wheelchairs meeting the definition of a "common wheelchair" must be transported whether they can be adequately secured or not. The current environment does not allow for draconian enforcement of whom and what are permitted aboard transit vehicles. Likewise, the wheelchair industry and medical insurers are not looking for new ways to complicate their already intricate requirements.

In the absence of a clear starting point, the suggestion can be made that the transit industry needs to reach out to stakeholders to begin formulating an approach. Recent developments at the federal level may point to possible venues. The meeting "National Dialogue on Accessible Transportation," was held in 2002 in Washington, D.C. The dialogue is being continued through a series of regional meetings in 2003, which could include focus on this topic. Also, a new RERC for accessible public transportation is being proposed by the NIDRR.

These efforts should acknowledge and coordinate the work already underway, hopefully with collaborative guidance from the FTA and its kindred federal agencies, Easter Seals' Project ACTION and the American Public Transportation Association as well as other interested industry and consumer organizations.

Accessibility and Intelligent Transportation Systems

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Overview

In the past few decades, intelligent transportation systems (ITS) have steadily evolved from research prototypes to successful commercial products. Certain trends in ITS provide key opportunities to reduce the cost of vehicle modification to end-consumers and third-party payers while also increasing the availability of technicians and vehicles.

Recent advances in ITS have been most apparent in passenger vehicles. Telematics (e.g., wireless, in-vehicle voice and data), in-vehicle navigation systems, adaptive or intelligent cruise control, vision enhancement systems, and automatic crash notification systems now are all available in U.S. showrooms. The added functionality of these systems has resulted in large shifts in driver-vehicle interface practices to reduce "button overload" and driver workload. The traditional practice of assigning one physical control per function is no longer an option. As such, the industry is moving toward new interaction models which, in many cases, directly affect accessibility.

Transit ITS applications are also becoming increasingly common. Real-time vehicle arrival estimates, electronic trip planning tools and smart card payment systems are already available in various metro areas around the United States. One of the most interesting and effective applications of traveler accessibility information, however, is the dissemination of out-of-service information for elevators and escalators (e.g., Washington, D.C. Metrorail). The opportunities and potential barriers are best illustrated through the examination of three general ITS trends that directly affect user-vehicle interactions: multifunction controls, voice interfaces and active vehicle controls.

Trend #1: Multifunction Controls

The use of a few controls to manage a large assortment of functions is starting to become common in high-end vehicles (e.g., BMW's iDrive system). Automobile manufacturers have a vested interest in promoting these new interfaces for branding and marketing purposes. For example, the Infinity Q45's multifunction system which offers a rear parking camera was the centerpiece of a heavily run advertisement campaign. As with antilock brakes, airbags and compact disc changers, products now available only on high-end vehicles will soon "trickle down" to the general market. The impact of multifunction systems on vehicle accessibility is relatively unknown, especially for drivers who use hand controls or have upper limb impairments.

Trend #2: Voice Interfaces

General Motors' OnStar® system has been the most successful telematics service provider in the United States, with more than 2 million subscribers since their initial deployment in the fall of 1996. Features include: concierge services, roadside assistance, route directions and emergency services. Other capabilities include remote door unlock, airbag deployment notification (currently about 688 per month) and theft protection. The OnStar® system's interface consists of three, closely grouped very small buttons in the car paired with a cellular connection to service centers. The call center uses a mixture of human operators and speech recognition software. All information is presented to the driver via audible speech. Although OnStar® could have great benefits to wheeled mobility users; it is not accessible to those with pronounced hearing loss or severe speech impairments. Also, persons with limited dexterity have restricted use due to the very small buttons.

Trend #3: Active Vehicle Control

A variety of vehicle-initiated actuation technologies, such as adaptive cruise control, lane keeping and collision avoidance systems, are already being introduced. The removal of the physical linkage between the steering wheel and the front wheels (drive-by-wire) is also on the horizon. The automotive community has begun the process of developing communications protocols, functions standards, software interfaces and specifications. This technology provides an opportunity to improve current vehicle control conversion methods and techniques by enabling a direct interface between alternative controls and the on-board vehicle control software.

Recommendations for Research

There has been considerable research on the usability and utility of ITS, and researchers often include older subjects in their studies. However, these volunteers are not representative of young and middle-aged users with disabilities. As such, the accessibility of ITS applications is largely unexplored. Furthermore, little effort has been devoted toward documenting and measuring interaction paradigms for appropriate and safe use by drivers and passengers with disabilities. Methodologies for detailed examination should include a mixture of proven techniques including, but not limited to, identification of user needs, guideline development, basic research, reference designs and prototype testing, and standards development.

Research is needed in the following areas to insure that new ITS adopted by industry are universally accessible. Some important topics in a research agenda should include the following:

- Multifunction dashboard controls that support safe use by drivers whose vehicles have hand controls or have upper limb impairment or have both. The opportunity to develop universal or easily modified interfaces is enhanced by the shift toward software-defined interfaces with generic physical controls. Methods and practices should be identified before standards and original equipment manufacturer practices are solidified.
- Driver-vehicle interfaces which support safe interaction by drivers who are deaf, hard of hearing or have speech impediments. As we have experienced with telematics and in-vehicle navigation systems, the advocates of accessibility and universal design have already missed having an impact on the first wave of products.
- Active vehicle control and drive-by-wire. As a long-range plan, the vehicle modification industry will benefit from early integration of alternative vehicle control software and hardware interfaces into active vehicle control and drive-by-wire standards.
- Accessible transit information. As transit agencies fall under the *Americans with Disabilities Act*, they have made concerted efforts to provide travelers' information in accessible formats.

Successful practices should be identified and disseminated within the industry to promote broader application.

There are significant opportunities for leveraging mainstream efforts and enthusiasm for new technologies to provide greater access to all travelers. ITS applications have the potential to be powerful enablers but, as demonstrated in the computer industry, barriers can be introduced inadvertently or can be a result of inadequate effort in identifying accessible solutions. A dedicated effort by policy and research entities to emphasize accessibility in the early stages of development will produce a significant benefit down the road.

Ingress and Egress From Vehicles

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Experience with the *Americans with Disabilities Act* (*ADA*) has demonstrated that providing accessibility for wheeled mobility devices is clearly feasible. But transit agencies and critics in the United States argue that the mandate to improve accessibility, combined with no increases or only minimal increases in budgets, hampers the ability of mass transit to compete with the private automobile. Although this may not be an accurate statement of fact, it is a perception that advocates and practitioners of accessible transportation have to address. Universal design is perhaps the way to counter this perception. Those in the accessibility movement must ally themselves closely with the advocates of mass transit in general because improving services and convenience for everyone are shared goals. Universal design includes traditional accessibility as required by the *ADA* and other laws, but that accessibility is provided in a way that benefits all customers not just the riders with disabilities.

A good example of universal design is the "stepless" bus. Conventional lift-equipped buses require special considerations for loading and unloading a wheeled mobility user. No one else benefits from those provisions. In fact, lifts do not even help people who have other disabilities. The stepless bus, equipped with a low floor, "kneeling" suspension and ramp access makes it easier for all riders to enter and exit, not just wheeled mobility users. It makes riding the bus more attractive to all customers and it makes the wheeled mobility user an independent rather than dependent participant.

We have definitely learned that accessible ingress and egress depends not only on the design of the vehicle but on the context in which the vehicle operates (e.g., station design, types of services provided and operating policies). Solutions that address both may be the most difficult to plan and implement but the benefits are worth it. For example, in Helsinki, Poland, the city has an extensive light rail system. Most of the major stops were located in the middle of the street on islands. A new tram was designed which had a low floor and wide midcar entry. A new fare system includes automated pay stations at each entry so all passengers can enter any door. The midstreet stops were raised off the ground to be flush with the low floor of the tram, and ramps were built at each end of the platforms. Another good example of universal design, this system increases safety and convenience in fare payment, and ingress and egress for all passengers.

Commuter and intercity rail systems present one of the greatest challenges to accessibility. There are a number of serious problems making these systems fully accessible. First, to increase the capacity of the system to a maximum, passenger cars are completely filled with seats, leaving only minimal room for luggage and wheeled mobility devices. Second, all compartments have stair access, often on two levels. Third, there can be a large gap between the train and the platform. Lastly, in some cases there also may be differences in the platform height from station to station. The new train that operates across the bridge from Denmark to Sweden is a good example of universal design. It has a low floor and a main entry in the middle of the car at the same level as the station platforms. Stairs lead from the middle to compartments at either end. The middle compartment is equipped with folding seats to provide more general room at peak periods for standing riders and also room for wheeled mobility devices, carriages, rolling luggage carts and bicycles. An accessible restroom is provided at that level. The entrance is equipped with a no-step entry, telescoping gangway to bridge the horizontal gap between train and platform, and a wide, automated entry door.

The graying of America will soon fuel a need to rethink how mass transportation services are provided on a communitywide level, especially in the low-density suburban areas of our cities. These projects will become the new frontier of accessible mass transportation. Two examples point the way to solutions for low-density communities.

> In Curitiba, Brazil, the city planners wanted a system that would be so convenient that no one would want to use private automobiles. The heart of the system is a dedicated busway with vehicles that hold up to 350 passengers. This capacity is achieved by having a minimum number of seats and "bus trains" with up to three articulated cars connected together. The bus trains travel on radial routes to the city center and a system of feeder buses bring passengers to the bus train terminals. The feeder buses are equipped with lifts for loading from street level, but once an individual is up at the floor level of the bus they can remain at that level using platform boarding at the terminals and at local downtown stops equipped with ramps or lifts. The Curitiba system is a very cost-effective approach that can be adapted to existing low-density areas where streets are wide enough to provide the dedicated busways. It could also be adopted on old railroad rights-of-way.
>
> In Sweden, future projections for the aging of the population indicated that the economic burden of paratransit for local transit systems would be immense. Therefore, the county's transportation agencies are implementing communitywide services using a mix of accessible vehicles. The most interesting are on-demand "flex routes" and "service routes." In the former, small buses with lifts travel a designated route in local areas picking up individuals at bus stops. The drivers are in communication with a dispatcher. When a request is received, the closest driver deviates from his route and picks up the passenger at the closest stop to their residence. On service routes, small buses carry up to 12 people or six wheelchairs. These buses are low-floor vehicles that also have lifts at a rear door. They follow a route that serves facilities frequented by frail, older people like rehabilitation hospitals, senior centers and senior housing facilities. The local neighborhood buses feed riders to stops where they can pick up these service route buses.

Citizens and governments are recognizing the importance of good mass transportation even in the United States—the most automobile-oriented country in the world. This new awareness offers opportunities to make strategic improvements in the accessibility of systems for wheeled mobility devices. There is much we can learn from the experiences in other countries where these issues are being addressed already. But as we move ahead, there is an important trend in wheeled mobility that must be addressed. Larger and heavier wheeled mobility devices are being used more frequently. Even lightweight wheelchairs, if they have cambered wheels, are wider than conventional models. Scooters and powered wheelchairs in particular have improved personal mobility for millions of people, but they also present problems in ingress and egress to mass transit vehicles. Ramps and lifts may not have the capacity for the occupied weight of some devices; there are bottoming-out problems when exiting ramps; the clearances inside the entries of the vehicles are not sufficient; and drivers cannot safely assist people with heavy devices to get up ramps and onto lifts. Thus, there is a need to start communications between consumer advocates, wheeled mobility device manufacturers, vehicle manufacturers and transit agencies to identify solutions to this growing problem. Some of the examples described above are good solutions (e.g., platform loading and low-floor center compartments). Nevertheless, other solutions are still needed such as design standards, operating guidelines and public education.

Categorization and Identification of Critical Research in Wheeled Mobility and Accessible Transportation

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In considering what research to pursue for wheeled mobility and accessible transportation it is worthwhile to categorize the different types of work that are needed. First, we identify engineering research as the research that must be done before an effective technology can be produced. Two examples of this are: 1) A likely candidate for improved wheelchair propulsion systems includes the use of mesoscale hydraulic actuators (a lifting cylinder powered by liquid under pressure with a variable range of extension) but before these actuators can be produced, there are varying fluid dynamics that must be understood and 2) To better understand the control system interface for a powered wheelchair control, more needs to be known about the human-machine interface, particularly with differences in user ability, before the control systems can be optimized.

Second is the area of design. The difference between engineering research and engineering design, in this context, is that useful products can be developed using formalized design procedures with what we currently know. For an example of something needing this type of design effort, consider a vehicle that is purpose-built from the original inception to be utilized by people using wheelchairs. More basic vehicle research is not necessary; however, in order to optimize the resultant vehicle design, formalized design methods are required.

Third is the area of clinical research. Clinical research is needed to ensure that a particular device, improvement or treatment, for example, is in fact resulting in the desired improvement. Much of the technology being considered here would benefit from clinical research; however, good design procedures ensure that user requirements are paramount in the resultant design, so perhaps there is overlap here that is unnecessary and costly.

Fourth is the area of sustainable production. If a device can be produced in a sustainable manner, then it is likely all sorts of things are true of that device. It must mean that is has consumer acceptance, medical and health insurance system acceptance, and in addition, an entity is able to produce it and survive financially. The primary goals of the engineering research, design or clinical research for wheeled mobility and accessible transportation are devices that are produced in a sustainable manner. The primary goal is not the generation of new knowledge. There are many other ways to generate new knowledge, and these methods should (and will be) fostered. The specific needs for wheeled mobility users are of sufficient magnitude and the resources sufficiently scarce that the focus should be on products and devices capable of sustainable production.

Finally, the fifth area of categorization is called state of the art. Technologies for wheeled mobility and accessible transportation will improve when there is a paradigm shift from good enough to state of the art. The INDEPENDENCE® iBOT™ 3000 mobility system is the best example of this in that the researchers and designers used the platform of a powered wheelchair to develop a device that led to the development of a new type of dynamic system. This paradigm shift will be beneficial for many reasons but there are two principal causes worth mentioning:

- This philosophy is a great motivator for both the developers and the users; and
- Multiple-use technologies are a result, with all of the benefits that occur from having devices that are useful to more than one audience.

One additional comment: There is no difference in the level of complexity, or the skill needed, or the creativity required between good engineering research, design, clinical research or development of products capable of sustainable production. The implication of this is important for selecting which projects to pursue. Decisions should not be based on which of the activities is the most academic—most scholarly—or of most immediate use to a user. The process should include an assessment of capability to complete the task, and an evaluation of the contribution of the project to a larger viewpoint of how the effort will impact the goal of sustainable production of devices.

Shown in the table below are lists of areas in wheeled mobility and accessible transportation that need attention. Space limits comments and descriptions, however, examination of the table will illustrate one set of ideas on how to prioritize work in this area. For example, when considering power systems for use in powered wheelchairs, effort is needed in all of the areas previously described; yet, it would be the best use of resources to do the research and design first and then follow with the other necessary work to produce a usable product.

Wheeled Mobility and Accessible Transportation: Selected Research Areas

Device	Area Needing Improvement	Type of Improvement Needed	Type of Effort Needed Now
Power Wheelchair	Power System	Weight, Size, Power Density, Cost, Range and Power	Research and Design
	Actuators	Weight, Size, Cost and Power	Research and Design
	Modularity	Ease of Customization and Transportability	Design and Sustainable Production
	Energy Storage System	Power, Range and Refueling	Design and Sustainable Production
	Control of Dynamics	INDEPENDENCE® iBOT™ 3000 Mobility System	Research and Design
	Wheelchair Restraint	User-activated and Standardized	Design and Sustainable Production
	Control Interface	Adaptability, Configurability and Feedback	Research
Personal Vehicle	Suitability	Original Equipment Manufacturer (OEM) Manufactured	Design and Sustainable Production
	Reliability	Same	Same
	Safety	Beyond Normal Vehicles	Same
	Cost	Consistent With the Equipment	Same
	Dual-use	OEM Manufactured	Same
Personal Restraint System	Safety	Beyond Normal Restraint Systems	Research and Design
	Usability	User-attachable	Design
	Aesthetics	Obvious	Design
	Cost	Consistent With Normal Restraint System Costs	Design
Public Transportation	Taxies	Entry and Exit	Design
	Buses	Restraint	Design
	Trains	Entry, Exit and In-wheelchair Seating	Design and Sustainable Production
	Airplanes	Entry, Exit, Wheelchair Transport and In-wheelchair Seating	Design and Sustainable Production

Topic: Standards for Public Transportation

Wheelchairs as Seats in Motor Vehicles

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Transit Wheelchair Standards

Wheelchair users who are unable to transfer to a motor vehicle seat during transport must rely upon their wheelchair to function as a vehicle seat. Wheelchair crashworthiness is addressed nationally through the American National Standards Institute/Rehabilitation Engineering and Assistive Technology Society of North America (ANSI/RESNA) WC-19 Wheelchairs Used as Motor Vehicle Seats standard, and internationally through the International Organization for Standardization (ISO) 7176/19 Wheelchairs Used as Motor Vehicle Seats standard (ANSI/RESNA 2000 and ISO 2000). These standards, which focus on the use of a wheelchair as a motor vehicle seat, propose design requirements, instructions to users and test procedures for wheelchairs intended for transportation. A significant design requirement established by these standards is the addition of four securement points on transport-safe wheelchairs which are compatible with end fittings of strap-type tie-down securement systems. This requirement was defined in response to difficulty in properly identifying locations on the wheelchair for attachment of tie-downs. Frontal impact crash testing is also required by the ANSI/RESNA WC-19 and ISO 7176/19 standards. This tested an appropriately sized, wheelchair-seated test dummy to a 20-g and 48-kilometer-per-hour frontal impact crash test. In the ANSI/RESNA WC-19 test protocol, the wheelchair is secured and the occupant is restrained using a reusable wheelchair tie-down and occupant restraint system. The ISO 7176/19-DIS test protocol permits wheelchair securement and occupant restraint using a commercial wheelchair tie-down and occupant restraint system. The ANSI/RESNA WC-19 and ISO 7176/19 test criteria assess wheelchair integrity, as well as occupant and wheelchair kinematics. Many manufacturers now offer transit option wheelchairs in the United States. Roughly 63 WC-19 tests of wheelchairs have been conducted over the past two years at the University of Michigan's Transportation Research Institute—the primary laboratory in the United States for WC-19 testing.

Despite the purpose of the ANSI/RESNA WC-19 and the ISO 7176/19 standards being used to evaluate wheelchair crashworthiness, the addition of aftermarket or optional wheelchair seating systems would invalidate wheelchair testing conducted with an original equipment manufacturer (OEM) seat. Consequently, wheelchairs utilizing aftermarket seating systems may not be crash tested to evaluate their ability to withstand crash-level forces. Additionally, replacement seating systems provided in the field, which differ from those provided with a WC-19- or ISO 7176/19-approved wheelchair, would invalidate compliance and will not be tested. Therefore, methods to evaluate wheelchair seating system crashworthiness, independent of different wheelchair frames, with which they may be coupled in the field are desirable. Toward this end, both the international and national standards groups have organized efforts to address aftermarket, transport-safe wheelchair seating. The ISO 16840-4 and the ANSI/RESNA's seating devices for use in motor vehicles working groups have been working toward such a standard. Both of these groups have agreed to pursue development of independent dynamic seating test methods. Efforts led to the development of a reusable wheelchair base, which is capable of crash testing commercial wheelchair seating systems independent of a specific wheelchair frame. Validation of the reusable wheelchair base is currently underway.

Published Research

Although most injury research and prevention fields are driven by epidemiology-based studies detailing accident statistics, only limited data on accidents involving persons using wheelchairs as seats in motor vehicle crashes are available (Calder and Kirby 1990, 184–90; National Highway Traffic Safety Administration 1997; Shaw 2000, 89–100; and Ummat and Kirby 1994, 163–67). Early wheelchair transportation research has primarily focused on efforts needed to advance standards development. These early studies worked toward the development of a repeatable frontal impact test using a reusable wheelchair (Shaw et al. 1994). As a part of the standards effort, a computer simulation model was used to investigate the effects of different elements (e.g., seated posture outcomes on wheelchair tie-down and occupant restraint systems and occupant crash response) (Kang and Pilkey 1998, 73–84). A number of studies have also attempted to investigate the injury risk associated with using a wheelchair as a motor vehicle seat, investigating the effects of crash pulse (Kang and Pilkey 1998, 73–84), securement point location (Bertocci, Diggs, and Hobson 2000, 126–39 and Kang and Pilkey 1998, 73–84), restraint configuration (Bertocci, Diggs, and Hobson 1996, 279–89; Bertocci and Evans 2000, 573–89; and Gu and Roy 1996), and seated posture (Kang and Pilkey 1998, 73–84).

Supporting the fact that wheelchairs are not typically designed to sustain crash-level forces, component testing studies have shown that casters—seat attachment hardware and seat support surfaces—often fail at loads similar to those imposed in a frontal impact crash (Bertocci, Ha, Deemer, et al. 2001, 534–40; Bertocci, Ha, van Roosmalen, et al. 2001, 249–57; Bertocci et al. 1999, 32–41; and Ha et al. 2000, 555–63). Unfortunately, design criteria to guide manufacturers in the development of transport-safe wheelchairs and wheelchair seating systems are relatively scarce. Information that exists in the literature has largely been derived from computer simulation of frontal impact events (Bertocci, Szobota, et al. 2000, 565–72; Bertocci et al., 1996, 171–81; and Gu and Roy 1996). These studies have shown that numerous factors (e.g., rear wheelchair securement location, seat stiffness and seat angle) can influence loads that wheelchairs are exposed to in a crash. These findings suggest that manufacturer design decisions can greatly impact the crashworthiness of wheelchairs. While performance of all wheelchair components is key to occupant crash protection, seat design and integrity are of particular concern since vehicle seat characteristics and failure have been linked directly to injury risk in motor vehicle crashes (Adomeit 1979; Aibe et al. 1982; Blaisdell et al. 1993, 109–19; National Highway Traffic Safety Administration 1997; Saczalski et al. 1993; Strother and James 1987, 225–43; Viano 1992; and Warner et al. 1991). Frontal impact crash tests (20 g and 48 kilometer per hour) of commercial wheelchairs have shown seating system failures to be relatively common (Schneider and Manary 2001). Seat attachment hardware, seat support surfaces and seat backs (on rebound) are among the most common components to fail under frontal impact conditions.

Previous studies which have attempted to elucidate wheelchair seat loading under crash conditions have consisted of both computer simulation studies and limited crash testing. Computer simulation studies have shown that frontal impact seat forces are dependent upon crash pulse, rear securement point location, seat characteristics and restraint configuration (Bertocci, Szobota, et al. 2000, 565–72; Bertocci et al., 1996, 171–81; Gu and Roy 1996; and Kang and Pilkey 1998, 73–84). A limited series of frontal impact crash tests conducted by Gu and Roy, with disc-type load cells (i.e., sensors in the load cell family dedicated to force measurement) incorporated into the ISO reusable wheelchair and using a Hybrid III 50th percentile male test dummy (i.e., a crash testing dummy measuring 5 feet 9 inches tall and 170 pounds, representing a man of average size), measured seat loads (Gu and Roy 1996). Shaw also estimated seat loading in frontal impact crash testing using pressure-sensitive film placed on the seat and load cells located beneath the front wheels of commercial manual wheelchairs with various types of seating systems (e.g., sling or rigid foam mounted on plywood) (ANSI/RESNA 1996). In these tests, Shaw estimated vertical seat loads and found that higher loads were associated with more rigid seating systems. Frontal impact testing (four tests) conducted by Bertocci and Manary, using the Society of Automotive Engineers reusable wheelchair, evaluated seat loads using disc-type load cells incorporated into the wheelchair seat and also evaluated the effects of rear securement-point location (Bertocci, Manary, and Ha 2001, 679–85). This recent series of crash tests provided validation to a previously conducted computer simulation study (Bertocci et al., 1996, 171–81).

While these previous studies represent a preliminary effort toward the development of transport-safe wheelchairs and wheelchair seating, additional efforts are needed to advance safe wheelchair transportation. Testing and computer simulations to date were conducted with a 50th percentile male test dummy; no published studies exist that have evaluated seating loads associated with child-sized test dummies. Recently the Rehabilitation Engineering Research Center (RERC) on Wheelchair Transportation Safety (RERC-WTS) has conducted such tests and is currently analyzing the data. Furthermore, previous studies evaluated seat loading in frontal impact conditions alone—only recently has the RERC-WTS begun to study seat loading under rear impact conditions that are likely to impose very different loading conditions. Failure of seat backs during the rebound phase of frontal impact testing also has led to efforts to evaluate seat back loading conditions within the RERC-WTS. Wheelchair seat backs also are subjected to unique loading conditions in rear impact crashes. Preliminary tests have been conducted by the RERC-WTS to evaluate seat back and wheelchair strength in rear impact collisions. Postural supports also present a unique challenge during transport but, unfortunately, have received very little attention related to transit-safe design. Clearly, additional guidance is needed to provide wheelchair and seating manufacturers with guidance related to the design of transport-safe wheelchairs. As more transit wheelchairs become available, wheelchair user safety will approach levels similar to that provided to OEM vehicle seat users—a scenario that must occur for equivalency in public accommodation.

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Appendix B:
Complete List of Research-related Issues and Needs Developed By Meeting Participants

Based on submitted papers, experts' presentations and group discussion, meeting participants generated a working list of 56 research-related issues and needs in three major areas. This list was refined and prioritized via teleconference after the summit. The final list is presented in the body of the proceedings. The complete list is provided here in the spirit of sharing all of the ideas generated by the summit participants.

Wheeled Mobility Usage and Interface With the Environment

1. A federally funded mechanism for early-phase development and implementation of standards (e.g., ISO and ANSI/RESNA) to include front-end high-risk funding (i.e., early, speculative funding of a research project that has very low probability of success).
2. Electronic interfaces that comport with standards for operability and third-party payment that comply with standards.
3. Evidence-based practice guidelines must inform reimbursement policy so individuals are able to obtain wheelchairs and seating systems through third-party carriers that can best assist their activities of daily living, without negatively impacting their medical condition, while addressing the standards of clinical practice.
4. Recommendation that the Interagency Working Group on Assistive Technology Mobility Devices receive input from the DOT and the U.S. Access Board to assist people with reimbursement issues for wheelchairs. (Note: This working group released its report in March 2004).
5. Funding for multisite clinical trials to prove the efficacy of research in order to get FDA approval and CMS reimbursement.
6. Power-assisted wheels for manual-style usage and other secondary conditions of power usage for people in transition as an intermediate style of power.
7. Increased knowledge and understanding of smart wheelchairs with respect to how they identify environmental situations and how they interact with the setting.
8. Use of ICF framework and structure within research and clinical applications in all phases of wheelchair usage.
9. Research regarding how people are trained to use mobility devices, then develop training guidelines for specific devices.
10. The impact of smart chairs on the mobility of people with a combination of physical, perceptual and cognitive disabilities.
11. Lack of research funding for physical fitness for wheelchair users. An example of how to potentially address this issue would be to increase coordination between the NIDRR and physical fitness programs, such as the President's Council on Physical Fitness and Sports. (A resource guide is available at: www.usc.edu/dept/gero/RRTConAging/paper1.html#anchor1, last accessed Dec. 19, 2004).
12. Funding for research to determine how the physical environment impacts the performance and needs of a smart chair.
13. Funding for longitudinal studies of 10–15 years in duration on wheelchairs and accessible transportation issues. No agency has a funding mechanism for implementing and reviewing longitudinal studies on aging.
14. Intervention studies that pertain to wheeled mobility and interface in the community with larger sampling and randomized clinical trials.
15. Studies with greater geographic representation, as well as more multicenter trials.

16. Increased number of studies with women and minorities.
17. Development of advanced mathematical and computer modeling in rehabilitation to be used for design of controls, upper extremity use for manual propulsion, smart chair operation in different environments, virtual reality and environmental detectors.
18. Build research capacity by:
    - Using training grants to develop expertise in young researchers, to include infrastructure and support facilities;
    - Establishing more core engineering in this area of research;
    - Coordinating existing resources; and
    - Funding high-level motion analysis, anthropometry and biomechanics labs.
19. Increase funding for the National Science Foundation's Research Experiences for Undergraduates and RERCs.
20. Anthropometry of wheeled mobility devices through the RERC on Universal Design at Buffalo and the U.S. Access Board, the government entity supporting this research, including coordination of resources across the government.
21. Increased information and long-term studies to investigate the cause and prevention of secondary injuries as a result of assistive technology use, such as arm pain in individuals who propel manual wheelchairs.

Safe and Accessible Transportation in Private and Public Vehicles

1. Modification of questions in national databases, such as the General Estimate System (www.transtats.bts.gov/databaseinfo.asp?DB_ID=600&DB_Name=General+Estimate+System&DB_URL=Subject_ID=1&Subject_Desc=Safety&Mode_ID2=0, last accessed Dec. 19 2004), the National Automotive-Field Sampling System (www-nrd.nhtsa.dot.gov/departments/nrd-30/ncsa/NASS.html, last accessed Dec. 19, 2004), the Fatal Accident Reporting System (www.nicar.org/data/fars, last accessed Dec. 19, 2004), the National Electronic Injury Surveillance System (www.cpsc.gov/cpscpub/pubs/3002.html, last accessed Dec. 19, 2004) and state police reports, to better determine, characterize and identify: 1) assistive technology use in transportation such as occupant restraint systems and 2) the crashes involving wheelchairs in motor vehicles—increase in number and quality of federal-level transit databases with nonproprietary software for researchers to use in giving a broader picture of use of transportation by wheelchair users and their involvement in crashes and incidents that result in injury.
2. A registry of wheelchair users willing to answer research questions to develop a user population that facilitates research and complies with the *Health Insurance Portability and Accountability Act*'s (http://www.hhs.gov/ocr/hipaa, last accessed May 11, 2006) privacy regulations; training of users to become active participants in framing research questions and design.
3. Identification of crashes or incidents in a timely manner for an in-depth investigation of people seated in wheelchairs: use of the FDA's MDRS for notification of when adverse events occur; the creation of an MDRS-capture transport accident subset, specifically for a listing of accidents that involve the transport of people in wheelchairs.
4. Research on risk analysis for a better balance of risk and operational issues based on vehicle type and transportation mode.
5. (a) Government funding of short-term research to assess the effectiveness of universal interfaces which can be used by manufacturers for wheelchair securement with motor vehicle seating, such as the four-point system. (b) Long-term research to explore a new universal interface design better than the four-point system.
6. Promotion of vehicle OEMs facilitating research and modification efforts to create a vehicle that is more universal to accommodate disabled passengers and drivers.
7. Examination of how younger people are interfacing with present systems.
8. Taking advantage of software and multifunction interfaces to support easy aftermarket modification—standards development for vehicle modification and software interfacing (for example, car rentals with hand controls should be universal and able to be installed quickly and easily.)
9. Promotion of the United States being more proactive in monitoring developments in other countries; the federal government in European countries pays for vehicle modifications, but federal-private partnership trends for vehicle modification in Europe are not coming to the United States because American automotive companies are afraid of liability.
10. Formation of partnerships for high-risk research so OEMs can do so without a lot of risk (e.g., the Intelligent Vehicle Initiative program for driver assistance.)
11. Federal government sponsorship of innovation programs for devices.
12. Investigation into whether Section 508 of the *Rehabilitation Act* applies to computer-like elements in the automotive industry to conform to assistive technology standards.

Standards for Public Transportation

1. Increased recognition of a wheelchair as a seat in a motor vehicle and the institution of federal standards giving endorsement to its use in transit.
2. The NHTSA to look at 30-mph crashtesting and 20-g standards for all school buses.
3. The establishment of reimbursement mechanisms to pay for wheelchairs that meet standards to serve as seats in a motor vehicle.
4. Research and data from accident reports concerning the wheelchair used as a seat in order to develop and study the efficacy and impact of standards so that people in transport chairs have fewer injuries during accidents.
5. Topical studies to identify means of reducing the incidence of injury, such as:
    a. The AHRQ's study of quality of health care and cost;
    b. Case studies of real-world incidents for manufacturers and providers;
    c. Education of people in absence of federal requirements; and
    d. Education of manufacturers' information derived from studies.
6. Address the manufacturers' liability issue by defining an acceptable level of consumer risk and considering their refusal to use four-point tie-downs as a liability issue.
7. Mandate a Department of Veterans Affairs adaptation of wheelchair criteria according to the WC-19 standard for wheelchair transit.
8. Research of accident investigation data to identify successful safety features.
9. Education of health-care providers on how to recommend devices with respect to transportation issues for transit vs. non-transit chairs.
10. Assessment of insurance plans for durable medical equipment benefits globally given the additional cost for transit chairs is not typically covered by Medicare.
11. Development of professional alliances between the universal design and smart growth communities to promote the adoption of universal design in public transportation.
12. Development of alternatives to paratransit systems such as:
    a. New forms of on-demand public transportation;
    b. Systems to meet the needs caused by changing demographics (e.g., growth of elderly population and single-parent households with children to transport); and
    c. Privately funded public transportation for children and the elderly in locations publicly funded systems do not serve.
13. Research to assess the level of compliance of private transportation companies that provide public accommodations given that the *ADA* encompasses these entities.
14. Research to determine whether standards should accommodate trends in larger-wheeled mobility devices, or if the devices should be designed to meet basic requirements for use on public transportation vehicles. Consider:
    a. Designing mobility devices for different uses and encouraging people to have more than one wheeled mobility device;
    b. Labeling wheelchairs to indicate what standards they meet, so consumers would be informed of the implications; and
    c. The design of equipment to fit the environment and accommodate tie-downs.
15. Modification of current reimbursement system to pay for equipment consumer needs for indoor and outdoor use.
16. The education of manufacturers on *ADA* and environment standards in order to promote a working relationship with consumers, clinicians and the U.S. Access Board.

17. Market research prohibition waivers for orphan-type technology.
18. Information on best practices in universal design in transportation.
19. Research on the assistance needs of passengers.
20. Research and development (R&D) on scooter design to develop smaller devices and improved maneuverability, especially for the home environment.
21. Engineering R&D in areas such as lifts, ramps for better designs, study materials and smart technologies. Evaluation of tie-downs, load, unload and driver role to create a more independent role for the user, the study of wheelchair lift and ramp use during transportation activities including transit operator acceptance of different devices and locations (e.g., rear, middle or front).
22. Assessment of attitudes and knowledge of consumers and practitioners about wheelchair choices for use in transport environments.

Appendix C:
Acronyms List

Acronym	Full Name
AC Transit	Alameda-Contra Costa Transit
ADA	*Americans with Disabilities Act*
AHRQ	Agency for Healthcare Research and Quality
ANSI	American National Standards Institute
ALS	Amyotrophic Lateral Sclerosis
BRT	Bus Rapid Transit
CCF	Cleveland Clinic Foundation
CDC	Centers for Disease Control and Prevention
CMS	Centers for Medicare and Medicaid Services
CUTR	Center for Urban Transportation Research
DOT	Department of Transportation
FDA	Food and Drug Administration
FMVSS	Federal Motor Vehicle Safety Standard
FTA	Federal Transit Administration
ICDR	Interagency Committee on Disability Research
ICF	International Classification of Functioning, Disability and Health
IMA	Intelligent Mobility Aids
ISO	International Organization for Standards
ITS	Intelligent Transportation Systems
MDRS	Medical Device Reporting System
MS	Multiple Sclerosis
NHTSA	National Highway Traffic Safety Administration
NIDRR	National Institute on Disability and Rehabilitation Research
NIH	National Institutes of Health
NFI	New Freedom Initiative
OEM	Original Equipment Manufacturer
R&D	Research and Development
RERC	Rehabilitation Engineering Research Center
RERC-WTS	Rehabilitation Engineering Research Center on Wheelchair Transportation Safety
RESNA	Rehabilitation Engineering and Assistive Technology Society of North America
SAE	Society of Automotive Engineers
SOWHAT	Standards Committee on Wheelchairs and Transportation
VA	Department of Veterans Affairs
WC-19	ANSI/RESNA WC-19: Wheelchairs Used as Seats in Motor Vehicles
WHO	World Health Organization

Appendix D:
Selected Web Site Resource List

Name[4]	Web Site Resource
Alameda-Contra Costa Transit District-Wheelchair Securement	www.actransit.org/pdf/securement.pdf
Center for Urban Transportation Research	www.cutr.usf.edu/index2.htm
Douglas J. Cross Transportation Consulting	www.douglasjcross.com
Interagency Committee on Disability Research	www.icdr.us
New Freedom Initiative	www.whitehouse.gov/news/freedominitiative/freedominitiative.html
Smile Rehab, Limited	www.smilerehab.com
Wheelchair Transportation Safety Frequently Asked Questions	www.rercwts.pitt.edu/RERC_WTS_FAQ/RERC_WTS_FAQ.html
Wheelchair Seating and Wheelchair Transportation Safety Standards	www.wheelchairstandards.pitt.edu

[4] This table includes a list of Web sites discussed within the presenters' prepared brief papers. The table represents an effort on the part of the ICDR to provide the reader with a list of these Web sites in a central location as a convenience. It is not intended to reflect a broad, across-the-board representation of resources available in general.

Appendix E:
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